

Description

[COMPOSITION OF NANO-TUBE COMPOSITE POLYMER ELECTROLYTE AND FABRICATION METHOD THEREOF]

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of Taiwan application serial no. 92108199, filed April 10, 2004.

BACKGROUND OF INVENTION

[0002] Field of the Invention

[0003] The present invention relates to an electrolyte, and more particularly to a composition of nano-tube composite polymer electrolyte and a fabrication method thereof.

[0004] Description of the Related Art

[0005] In 1973, Wright et al. mixed polyethylene oxide (PEO) and KSCN for forming a crystal complex. In 1975, they further proved that the complex had a conductivity higher than 10^{-4} S/cm at high temperature (> 100 °C). PEO salt could have conductivity about 10^{-3} S/cm similar to that of or-

ganic electrolyte solution at 100 °C. Then, more research and study were undertaken for improving the conductivity of the polymer electrolyte at room temperature and achieving practical application.

[0006] Generally, the polymer electrolyte is made of a polymer substrate and a metal salt. In the amorphous region of the polymer substrate, the metal salt interacts with functional groups of the polymer so that the metal salt moves along the chains of the polymer for transmitting the metal ions.

[0007] For the time being, the systems of polymer electrolyte includes Polyethylene Oxide (PEO), Polyvinylidene Fluoride (PVDF), Poly(methyl Methacrylate) (PMMA), Polyvinylidene chloride (PVC), Polyacrylonitrile (PAN), etc. The cations of the metal salt can be, for example, Li, Na, K, Mg, etc; the anions can be BF_4^- , SCN^- , SO_3CF_3^- , AsF_6^- , PF_6^- , $\text{N}(\text{CF}_3\text{SO}_3)^-$, etc. The bigger anion group has higher delocalized charges and easily ionizes.

[0008] Generally, the conductivity and the mechanical properties of the electrolyte can be improved by adding organic material for inhibiting the crystallization of the polymer, reducing T_g , enhancing the mobility of ions. It also can be achieved by selecting a proper salt with effectively dissociation property for enhancing the mobility of ions in the

electrolyte. U.S. Pat. No. 5,643,490 disclosed a method of manufacturing a polymer containing tetraalkylammonium. U.S. Pat. No. 5,688,613 disclosed a method of doping-polybenzimidazole with H_3PO_3 . U.S. Pat. No. 5,581,394, 5,705,084, 5,645,960, 5,731,104, 5,609,974 and 5,586,001 disclosed a method of adding organic plasticizers such as Ethylene Carbonate (EC), Propylene Carbonate (PC) or Dimethylcarbonate (DMC) into polymer electrolytes. Although these methods can improve the conductivity of the solid-state electrolyte at room temperature, they will create other problems. Under high temperature and pressure, the electrolyte has bad thermal stability, softens and causes circuit shortage within cells.

[0009] The modifier can be inorganic material, such as nanoparticle TiO_2 in addition to organic material. Although the inorganic modifier can improve the mechanical properties of the polymer electrolyte, form a good interface between electrodes and the electrolyte, reduce the sediment of Li ions and extend the service life of battery, the conductivity and distribution of the electrolyte are not desirable at room temperature.

SUMMARY OF INVENTION

[0010] Accordingly, an objective of the present invention is to

provide a composition of a nano-tube composite polymer electrolyte and a fabrication method thereof, wherein a nano-tube modifier is added into the polymer electrolyte for enhancing the conductivity thereof.

[0011] The other objective of the present invention is to provide a composition of a nano-tube composite polymer electrolyte and a fabrication method thereof, which have excellent ionic conductivity, and good mechanical and process properties. Therefore, they can be applied to high-energy Li secondary cell or other electrochemical devices, such as super capacitors or sensors.

[0012] The present invention discloses a composition of a nano-tube composite polymer electrolyte, which comprises a polymer substrate having main-chains and side-chains, which have at least a Lewis base functional group; a metal salt, which can form a polymer salt complex with the polymer substrate; and a nano-tube modifier, which can form Lewis acid-base force with the polymer substrate and the polymer salt complex.

[0013] With regards to the polymer substrate, it has main-chains and side-chains, which at least have an ether group, an acyl group, an amino group, a fluoro group or a Lewis base functional group. The polymer substrate can be

polyalkylene oxide, polyvinyl fluoride, polyacrylonitrile, polyester, polyether, polysulfone, polyethylene oxide, polyvinylidene fluoride, poly(methyl methacrylate) (PMMA), polysiloxane, polyphosphazene or derivatives thereof. The Lewis base functional group includes oligo(oxyalkylene), fluoralkyl group, fluoralkylene group, carbonate group, cyano group and sulfonyl group.

[0014] The metal salt comprises a metal cation and an anion, which includes salt formed of alkaline-earth metal, alkali metal and transitional metal, such as LiPF_6 , LiAsF_6 , LiBF_4 , LiClO_4 , $\text{LiN}(\text{SO}_2\text{CF}_3)_2$, LiSbF_6 and $\text{LiSO}_3(\text{CF}_3)_2$, wherein n is 1~12. The metal salt forms a polymer salt complex with the polymer substrate.

[0015] The nano-tube modifier can enhance the conductivity and property of the polymer electrolyte. The surface of the nano-tube modifier has functional groups OR and O. The functional groups form Lewis acid-base interactions with the polymer substrate and the polymer salt complex. The nano-tube modifier includes TiO_2 , SiO_2 or Al_2O_3 with different crystal structures. The diameter (length) of the nano-tube modifier is, for example, about from 20 nm to about 160 nm. The aspect ratio (length/width) of the nano-tube modifier is more than 8. Because the total sur-

face area of the nano-tube modifier is larger than that of nano-particle (therefore, even larger compared to a micro-sized particle) and the nano-tube modifier is hollow, the interfacial interaction between the tube modifier and the polymer substrates establishes strong surface charge field. This unique structure characteristic has lead to tremendous improvements in physical properties, including ion conductivity displayed in the present invention. Furthermore, the metal cations can go through or be temporarily stored therein.

[0016] The present invention also discloses a method for fabricating a nano-tube composite polymer electrolyte, comprising: mixing a nano-tube modifier and an anhydrous solvent, adding metal salt into the solution and then adding a polymer substrate therein; heating and completely stirring the mixed solution for generating a uniform polymer electrolyte; and coating the uniform polymer electrolyte on a plate electrode, a container or a surface of an object and removing the solvent for forming a polymer electrolyte film.

[0017] In the method for fabricating a nano-tube composite polymer electrolyte of the present invention, the anhydrous solvent comprises tetrahydrofuran (THF) having a

dielectric constant higher than 20. During the step of stirring, it is performed with the assist of microwave or ultrasonic for completely mixing. After forming the polymer electrolyte film, an electrical field treatment is performed at a temperature higher than a T_g of the polymer and cooling down to room temperature for enhancing the conductivity thereof.

[0018] The nano-tubes of the composite polymer electrolyte of the present invention are formed by a base treatment to nano particles for forming the tube shape. During the process of forming the composite polymer electrolyte, the nano-tubes are stirred with the polymer substrate by ultrasonic for achieving high uniformity. Moreover, the nano-tubes of the composite polymer electrolyte, the metal salt and the Lewis base functional group of the polymer substrate can form a complex, which can enhance the ratio of amorphous region and dissociation of the metal salt for improving the conductivity of the polymer electrolyte.

[0019] Furthermore, the dielectric constant of the nano-tubes of the composite polymer electrolyte of the present invention is higher than 183. By heating or electrical field treatment, the nano-tubes will be arranged in order and the dielec-

tric constant of the composite polymer electrolyte will be increased as to enhance the conductivity thereof by one to three orders. It will have better performance than that of the traditional polymer electrolyte. Accordingly, the resistance of device using the electrolyte will has low resistance, better electrical properties at low temperature and longer service time.

[0020] In order to make the aforementioned and other objects, features and advantages of the present invention understandable, a preferred embodiment accompanied with figures is described in detail below.

BRIEF DESCRIPTION OF DRAWINGS

[0021] FIG. 1 TEM picture of nano-particle TiO_2 .

[0022] FIG. 2 TEM picture of nano-tube TiO_2 .

[0023] FIG. 3 is a relationship between temperature and conductivity of experiments 9 and 10.

[0024] FIG. 4 is a relationship between temperature and conductivity of experiments 12, 15, 17 and 19.

DETAILED DESCRIPTION

[0025] The nano-tube composite polymer electrolyte of the present invention comprises a polymer substrate, a metal salt and a nano-tube modifier.

[0026] The polymer substrate has, for example, main-chains and side-chains, which at least have an ether group, an acyl group, an amino group, a fluoro group or a Lewis base functional group. The polymer substrate has amorphous region between the melting point thereof and a temperature. As to the polymer substrate of the present invention, it can be polyalkylene oxide, polyvinyl fluoride, polyacrylonitrile, polyester, polyether, polysulfone, polyethylene oxide, polyvinylidene fluoride, poly(methyl methacrylate) (PMMA), polysiloxane, polyphosphazene or derivatives thereof. The Lewis base functional group includes oligo(oxyalkylene), fluoralkyl group, fluoralkylene, carbonate group, cyano group or sulfonyl group.

[0027] The metal salt comprises a metal cation and an anion, which includes, for example, salt formed of alkaline-earth metal, alkali metal and transitional metal. The anion is, for example, ClO_4^- , $\text{S}_2\text{O}_8^{2-}$, BF_4^- , AsF_6^- , PF_6^- and TeF_6^- . The metal salt can be, for example, LiPF_6 , LiAsF_6 , LiBF_4 , LiClO_4 , $\text{LiN}(\text{SO}_2\text{CF}_3)_2$, LiSbF_6 and $\text{LiSO}_3(\text{CF}_2)_n\text{CF}_3$, wherein n is 1~12. The metal salt forms a polymer salt complex with the polymer substrate.

[0028] The nano-tube modifier can enhance the conductivity and property of the polymer electrolyte. The surface of the

nano-tube modifier has functional groups OR and O . The functional group will form Lewis acid-base force with the polymer substrate and the polymer salt complex. The nano-tube modifier includes TiO_2 , SiO_2 or Al_2O_3 with different crystal structures. The diameter of the nano-tube modifier is, for example, about from 50 nm to about 160 nm. The aspect ratio (length/width) of the nano-tube modifier is higher than 8. Because the total surface area of the nano-tube modifier is larger than that of a nanoparticle and the nano-tube modifier is hollow, the metal cations can go through or be temporarily stored therein.

[0029] The nano-tube composite polymer electrolyte of the present invention comprises the polymer substrate about from 30% to about 90% by weight; the metal salt about from 2% to about 30% by weight; and the nano-tube modifier about from 3% to about 30% by weight. It also can comprise the polymer substrate about from 60% to about 90% by weight; the metal salt about from 2% to about 50% by weight; and the nano-tube modifier about from 1% to about 20% by weight. Moreover, the weight-average molecular weight of the polymer substrate should be high enough to establish free standing film. This character can vary from polymer to polymer but typically it varies from

about 1000 to about 1,000,000.

[0030] The nano-tube composite polymer electrolyte of the present invention comprises the polymer substrate, the metal salt and the nano-tube modifier. The enhancement of the conductivity of the polymer electrolyte results from the dissociation of the metal salt at the disordered area of the polymer substrate. Under the interaction between the ions and atoms of the polymer, the ions diffuses within the polymer following the direction of the magnetic field for conduction.

[0031] Moreover, because of the addition of the nano-tube modifier into the composite polymer electrolyte, the nano-tube composite polymer electrolyte of the present invention exhibits better mechanical and process properties than those composites with ordinary nano particles. The conductivity of the nano-tube composite polymer electrolyte can be improved under room temperature. Because the interaction force formed by the nano-tubes with metal salt is larger than that formed by nano particles, the dissociation of the metal salt is enhanced and the space for Li ions is also increased. Therefore, the conductivity is enhanced.

[0032] Additionally, the nano-tube modifier added into the com-

posite polymer electrolyte of the present invention enhances the dissociation of the metal salt. The ionized Li ions enter the crystal structure of the polymer substrate for forming a complex having a structure similar thereto and reducing the crystallization thereof. Therefore, the free space of the solid-state composite polymer electrolyte is increased and the dissociated metal salt goes into the hollow structure of the nano-tubes which establishes additional transporting channel for ions transport. Therefore, the conductivity of the nano-tube composite polymer electrolyte is better than that of composite polymer electrolyte with nano particles.

[0033] Moreover, when the solid-state composite polymer electrolyte film of the present invention is applied to an electrochemical cell, the composite polymer electrolyte film made of the polymer substrate, the metal salt and the nano-tube modifier can improve the isolation between electrodes and avoid electrode shortage resulting from the contact of dendrimers of the electrodes.

[0034] In addition, adding the nano-tube modifier into the composite polymer electrolyte not only improves the mechanical property thereof, but also enhances the dissociation of the metal salt as to improve the conductivity of the Li ions

of the electrolyte.

[0035] The method for fabricating a nano-tube composite polymer electrolyte of the present invention comprises: mixing a nano-tube modifier and an anhydrous solvent, adding metal salt into the solution and then adding a polymer substrate therein; heating and completely stirring the mixed solution for generating a uniform polymer electrolyte; and coating the uniform polymer electrolyte on a plate electrode, a container or a surface of an object and removing the solvent for forming a polymer electrolyte film.

[0036] In the method for fabricating a nano-tube composite polymer electrolyte of the present invention, the anhydrous solvent can be, for example, tetrahydrofuran (THF) having a dielectric constant higher than 20. Other solvents with suitable solubility also served the purpose. During the step of stirring, it is performed with the assist of microwave or ultrasonic for completely mixing. After forming the polymer electrolyte film, an electrical field treatment is performed at a temperature higher than a T_g of the polymer and cooling down to room temperature for enhancing the conductivity thereof. The electrical field of the electrical field treatment is from about 200 to about

10,000 V/cm, and the process time is from about 1 hr to about 90 hrs.

[0037] The method for fabricating a nano-tube TiO_2 of the present invention first forming nano-particle TiO_2 by Sol-Gel. A base refinement, such as using NaOH as a refiner, for forming nano-tube TiO_2 , wherein the temperature of the base refinement is from about 100 °C to about 300 °C and the heating time is from about 1 hr to about 50 hrs. When the refinement is done, the rate of the cooling down step is from about 30 °C/hr to about 50 °C/hr and it is cooled down to room temperature. This method is more simple and convenient than the traditional method for preparing the nano-tubes. The present invention uses a strong base solution, such as 10M NaOH solution, to break down the bonds of TiO_2 for forming Ti-O-Na and Ti-OH. At this moment, the nano-particles have a multi-layer structure. An acid solution, such as HCl solution, is then used for reforming the bonds of TiO_2 . Finally, pillar type and hollow nano-tube TiO_2 is formed.

[0038] Following are the descriptions of the method for fabricating the nano-tube TiO_2 , the nano-tube composite polymer electrolyte and the fabrication method thereof.

[0039] This embodiment is the method for fabricating the nano-

tube TiO_2 . First, nano-particle TiO_2 is formed by Sol-Gel preparation method. Then, the crystal structure of the particles, anatase, is identified by XRD. TEM serves to find out the shape, particle size and distribution thereof. FIG.1 shows the nano-particles exists in chain. The nano-particle TiO_2 is oval and about 20~50 nm.

[0040] Then, a base refinement method is performed for forming nano-tube TiO_2 . First, TiO_2 and a 10 M NaOH solution having 100 times volume of the TiO_2 are provided in a Teflon cup. It is preferred that the volume ratio of the NaOH solution to the TiO_2 is more than 200. They are stirred for an hour and then put into an auctoclave for baking 1~50 hrs at 100~300 °C. When the reaction is complete, the rate of the cooling down step is from about 30 °C/hr to about 50 °C/hr and it is cooled down to room temperature. White powder sediments appear within the solution.

[0041] The powder is extracted by using a centrifuge. A 1N HCl solution is mixed with the powder, and the powder is then extracted again. The process is repeated for several times. De-ionized water is used to wash the powder until the PH of the solution is near to 7. The oval nano-particle TiO_2 transforms into hollow nano-tubes. The nano-tube TiO_2

is then dried at temperature lower than 50 °C.

[0042] XRD is then used to identify the structure of the nano-tube TiO_2 , wherein the structure includes anatase and rutile. When the 10 M NaOH solution is added to the TiO_2 , the structure of the TiO_2 changes and is a disordered structure. When the 1N HCl solution is added thereto, the nano-tube TiO_2 is formed.

[0043] Then, the nano-tube TiO_2 is put into a solvent and shook by ultrasonic for avoiding clusters resulting because of the interaction of surface charges. The particle size, shape and distribution are found out by TEM as shown in FIG. 2. The arrangement of the nano-tube TiO_2 is disordered, and the shape is changed from particles into hollow tubes, which have a length/width ratio of about 8. The dimension and aspect ratio of the tube can be tailored by changing the reaction concentrations and growth temperature and pressure.

[0044] The following embodiment is the method for forming the polymer electrolyte. An anhydrous solution, such as THF, having a dielectric constant larger than 20 is added to the nano-tube TiO_2 , and shook the solution for about 40~50 minutes for uniformly mixing the nano-tube TiO_2 therein. LiClO_4 is then added into the solution and stirred until full

dissolution. A portion of LiClO_4 goes into the nano-tube TiO_2 . A PEO polymer with specific ration to Li is added into the solution for forming the polymer electrolyte. Then the solution is heated and stirred at $65\sim 75\text{ }^\circ\text{C}$ for about $20\sim 24$ hrs. PEO will completely dissolve therein. The polymer electrolyte is then put into a Teflon dish or Petri-dish and most of the solvent is removed at $40\sim 60\text{ }^\circ\text{C}$. In order to make sure the removal of the solvent and water, the polymer electrolyte film is kept in a vacuum baker for $3\sim 7$ days. Then the solid-state polymer electrolyte film is kept under Ar environment for measuring the conductivity thereof.

[0045] Following are the experiments 1~19 for interpreting the properties of the polymer electrolyte of the present invention according to different processes.

[0046] In experiments 1~7, PEO is added into nano-particle TiO_2 or nano-tube TiO_2 . A solvent, THF, is added into different types of TiO_2 powder and shook by sonication for $40\sim 50$ minutes. POE with a specific ratio is added thereto, and heated and stirred at $60\text{ }^\circ\text{C}$ for about $20\sim 24$ hrs. The solvent is then removed by using a vacuum baker for forming a polymer film with thickness $20\sim 400\text{ }\mu\text{m}$. Thin film is kept in vacuum for $2\sim 3$ days and then under Ar environ-

ment.

- [0047] In experiments 8~19, PEO and LiClO_4 are added into nano-particle TiO_2 or nano-tube TiO_2 . A solvent, THF, is added into different types of TiO_2 powder and shook by ultrasonic for 40~50 minutes. LiClO_4 with a specific ratio is added thereto and stirred for about 10 minutes. POE with a specific ratio is added thereto, and heated and stirred at 60 °C for about 20~24 hrs for full dissolution. The solution is then poured into a Teflon dish or Petri-dish. The solvent is then removed by using a vacuum baker for forming a polymer film with thickness 20~400 μm . Thin film is kept in vacuum for 2~3 days and then under Ar environment.
- [0048] The compositions of the experiments 1~19 are shown in Table 1. The crystallization and appearance of the polymer electrolyte of the experiments 1~19 are summarized in Table 2. The polymer electrolyte films of the experiments 1~19 are processed by a 1000V/cm electrical field at 80 °C, and cooled down to room temperature. The changes of the conductivity and surface appearance of the films are shown in Table 3.
- [0049] Following are the results of the experiments 1~19. By TEM, the size of the nano-particle TiO_2 is about 20~50

nm. The nano-tube TiO_2 processed by the NaOH solution bears a length of about about 100~160 nm. In experiments 1~7, PEO generates different crystallizations depending on different nano TiO_2 . When PEO is added to nano-particle TiO_2 or nano-tube TiO_2 which have the same ratio, the nano-tube TiO_2 destroys the crystallization of the polymer more efficiently than nano-particle TiO_2 . Therefore, a more elastic and uniform polymer film is formed. As shown in Table 3, by thermal and electrical treatments the dielectric constant and conductivity of the polymer film is increased because charges affect the nano-tube TiO_2 without changing the appearance and mechanical properties thereof.

[0050] In experiments 8~19, the comparison of adding PEO and LiClO_4 into nano-particle TiO_2 or nano-tube TiO_2 is presented. When the ratio of LiClO_4 is less than 18%, the ionized LiClO_4 will not affect the crystallization of the polymer seriously. When the ratio of LiClO_4 is larger than 18%, the crystallization of PEO is totally destroyed and the electrolyte film will have bad mechanical properties. Then the nano-tube TiO_2 strengthens the mechanical properties of the film which can be performed by 3% nano-tube TiO_2 .

[0051] FIG. 3 is a relationship between temperature and conduc-

tivity of experiments 9 and 10. FIG. 3 demonstrated that the nano-tube TiO_2 facilitated the storage and transmission of Li ions. At room temperature, they displayed similar results: $2.2 \times 10^{-6} \text{ S/cm}$ for experiment 9 and $2.0 \times 10^{-6} \text{ S/cm}$ for experiment 10. When temperature is up, the crystallization of the polymer electrolyte film is down and the mobility of Li ions is enhanced. Therefore, when the temperature is higher than the melting point of the polymer electrolyte, the conductivity will increase. The increase of the ion conductivity is more pronounced for the nano-tube TiO_2 composite polymer electrolyte because the electrical field applied thereto arranges nano-tubes in order and enhances couple effect, which improves the dielectric constant thereof. Under high temperature, Li ions stored in the nano-tube TiO_2 will move out and result in the increase of the dissociation of the metal salt. When the polymer electrolyte is cooled down to room temperature, the conductivity is enhanced. Accordingly, the conductivity of the polymer electrolyte with nano-tube TiO_2 as shown in experiment 10 is increased to $4.5 \times 10^{-5} \text{ S/cm}$; the conductivity of the polymer electrolyte with nanoparticle TiO_2 as shown in experiment 9 is increased to $1.2 \times 10^{-5} \text{ S/cm}$. The similar results appear in experiments

12 and 17 which are polymer electrolyte with 5% nano-tube TiO_2 by weight. Invariably, better conductivity increase is found for those polymer electrolyte with nano-tube TiO_2 . After the treatment, the conductivity occurs in the range of 10^{-4} S/cm. FIG. 4 is a relationship between temperature and conductivity of experiments 12, 15, 17 and 19. In FIG. 4, the conductivities of the electrolytes with different ratios of Li salt added with nano-tube TiO_2 can generate similar improvement. 3% nano-tube TiO_2 can make obvious improvement. Under 1000V/cm electrical field and at 80 °C, they have the results similar to those measured by the variable temperature measurement. The best improvement of conductivity is over 20%. When the polymer electrolyte film is cooled down to room temperature, its mechanical properties can be recovered and the resistance thereof is also reduced because of the rearrangement of the nano-tubes. The devices using the electrolyte film can have long service time.

[0052] The nano-tubes of the composite polymer electrolyte of present invention are formed by a base treatment. During the process for fabricating the composite polymer electrolyte, the high uniformity and high particle dispersion is achieved by using ultrasonic. The nano-tubes of the

solid-state compositepolymer electrolyte, the metal salt, the Lewis base functional group form a complex which can improve the disordered area ratio of the polymer substrate, enhance the dissociation of the metal salt and increase the conductivity thereof.

[0053] Moreover, the dielectric constant of the nano-tubes of the compositepolymer electrolyte of the present invention is higher than 183. By heating or electrical field treatment, the nano-tubes will be arranged in long range order and the dielectric constant of the compositepolymer electrolyte will be increased as to enhance the conductivity thereof by one to three orders. It will have better performance than that of the traditional compositepolymer electrolyte. Accordingly, the resistance of device using the electrolyte low resistance, better electrical properties at low temperature and longer service time.

Table 1

	w%				mmole ratio		
	Nano-tube TiO ₂	Nano-particle TiO ₂	PEO	LiClO ₄	TiO ₂	PEO	LiClO ₄
Experiment 1	0	0	100	0	0	5	0
Experiment 2	0	3	100	0	37.5	5	0
Experiment 3	3	0	100	0	37.5	5	0
Experiment 4	0	5	100	0	62.6	5	0
Experiment 5	5	0	100	0	62.6	5	0
Experiment 6	0	10	100	0	125.2	5	0
Experiment 7	10	0	100	0	125.2	5	0
Experiment 8	0	0	90	10	0	5	104.3
Experiment 9	0	3	90	10	41.7	5	104.3
Experiment 10	3	0	90	10	41.7	5	104.3
Experiment 11	0	5	90	10	69.5	5	104.3
Experiment 12	5	0	90	10	69.5	5	104.3
Experiment 13	0	0	82	18	0	5	206.1
Experiment 14	0	3	82	18	45.8	5	206.1
Experiment 15	3	0	82	18	45.8	5	206.1
Experiment 16	0	5	82	18	76.3	5	206.1
Experiment 17	5	0	82	18	76.3	5	206.1
Experiment 18	0	0	80	20	0	5	234.7
Experiment 19	3	0	80	20	46.9	5	234.7

Table 2

	Enthalpy (j/g)	Crystallization (%)	Appearance
Experiment1	134	100	translucent, tough, little-hard film
Experiment2	130	97	low-transparent, soft, elastic film
Experiment3	119	89	low-transparent, soft, elastic film
Experiment4	103	77	low-transparent, soft, elastic film
Experiment5	85	63	low-transparent, soft, elastic film
Experiment6	68	51	low-transparent, soft, elastic film
Experiment7	54	40	low-transparent, soft, elastic film
Experiment8	72	54	translucent, soft, elastic film
Experiment9	63	47	light-white, soft, elastic film
Experiment10	70	52	light-white, soft, elastic film
Experiment11	59	44	light-white, soft, elastic film
Experiment12	62	46	light-white, soft, elastic film
Experiment13	0	0	opaque, soft, fragile film
Experiment14	0	0	white, soft, elastic film
Experiment15	0	0	white, soft, elastic film
Experiment16	0	0	white, soft, elastic film
Experiment17	0	0	white, soft, elastic film
Experiment18	0	0	opaque, soft, fragile film
Experiment19	0	0	white, soft, elastic film

Table 3

	Conductivity at R.T. (S/cm)	Conductivity after thermal treatment (S/cm)	Appearance after thermal treatment
Experiment1	2.96×10^{-10}	3.5×10^{-10}	translucent, tough, little-hard film
Experiment2	3.2×10^{-8}	6.8×10^{-8}	low-transparent, soft, elastic film
Experiment3	9.3×10^{-8}	3.6×10^{-7}	low-transparent, soft, elastic film
Experiment4	8.5×10^{-8}	1.3×10^{-7}	low-transparent, soft, elastic film
Experiment5	9.7×10^{-8}	2.7×10^{-7}	low-transparent, soft, elastic film
Experiment6	2.7×10^{-7}	4.9×10^{-7}	low-transparent, soft, elastic film
Experiment7	7.2×10^{-7}	6.6×10^{-7}	low-transparent, soft, elastic film
Experiment8	3.0×10^{-6}	8.2×10^{-6}	translucent, tough, little-hard film
Experiment9	2.2×10^{-6}	1.2×10^{-5}	light-white, soft, elastic film
Experiment10	2.0×10^{-6}	4.5×10^{-5}	light-white, soft, elastic film
Experiment11	6.3×10^{-6}	2.1×10^{-5}	light-white, soft, elastic film
Experiment12	5.4×10^{-6}	5.3×10^{-5}	light-white, soft, elastic film
Experiment13	1.2×10^{-5}	6.8×10^{-5}	opaque, soft, fragile film
Experiment14	1.6×10^{-5}	0.5×10^{-4}	white, soft, elastic film
Experiment15	1.7×10^{-5}	2.4×10^{-4}	white, soft, elastic film
Experiment16	1.3×10^{-5}	0.7×10^{-4}	white, soft, elastic film
Experiment17	1.1×10^{-5}	2.7×10^{-4}	white, soft, elastic film
Experiment18	4.3×10^{-5}	7.4×10^{-5}	opaque, soft, fragile film
Experiment19	4.7×10^{-5}	2.9×10^{-4}	white, soft, elastic film

[0054] Although the present invention has been demonstrated by

exemplary embodiments, it is not limited thereto by these experiments. Rather, the appended claims should be constructed broadly to include other variants and embodiments of the invention, which may be made by those skilled in the field of this art without departing from the scope and range of equivalents of the invention.